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(54) **HIGH PRESSURE DIRECT INJECTED
GASEOUS FUEL SYSTEM AND RETROFIT
KIT INCORPORATING THE SAME**

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123/521, 525, 557
See application file for complete search history.

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(57) **ABSTRACT**

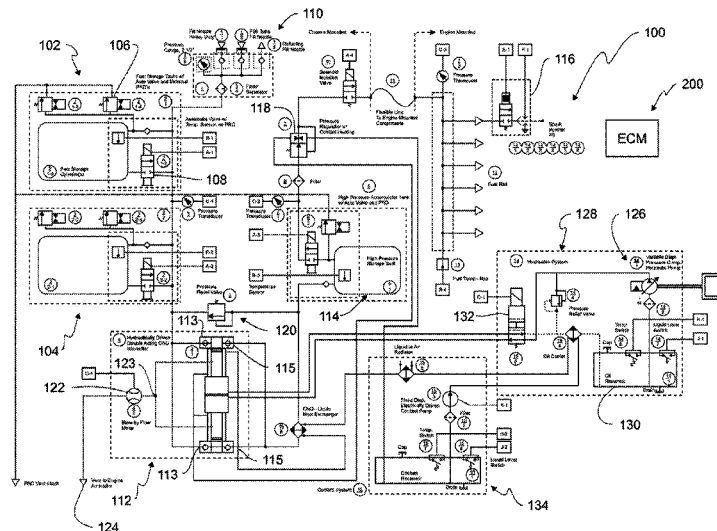
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A high-pressure direct injected gaseous fuel system comprising a fuel tank capable of storing fuel at a first pressure and a compressor including an inlet capable of receiving the fuel, and operative to supply, at an outlet, compressed fuel at a second pressure higher than the first. The system also includes an accumulator connected to the outlet and a plurality of injectors connected to the accumulator. The injectors are adapted to inject fuel directly into a combustion chamber. The system includes a pressure relief valve interconnecting the fuel tank and the outlet, wherein the pressure relief valve is operative to allow fuel flow between the fuel tank and outlet if the second pressure exceeds a threshold pressure.

19 Claims, 1 Drawing Sheet



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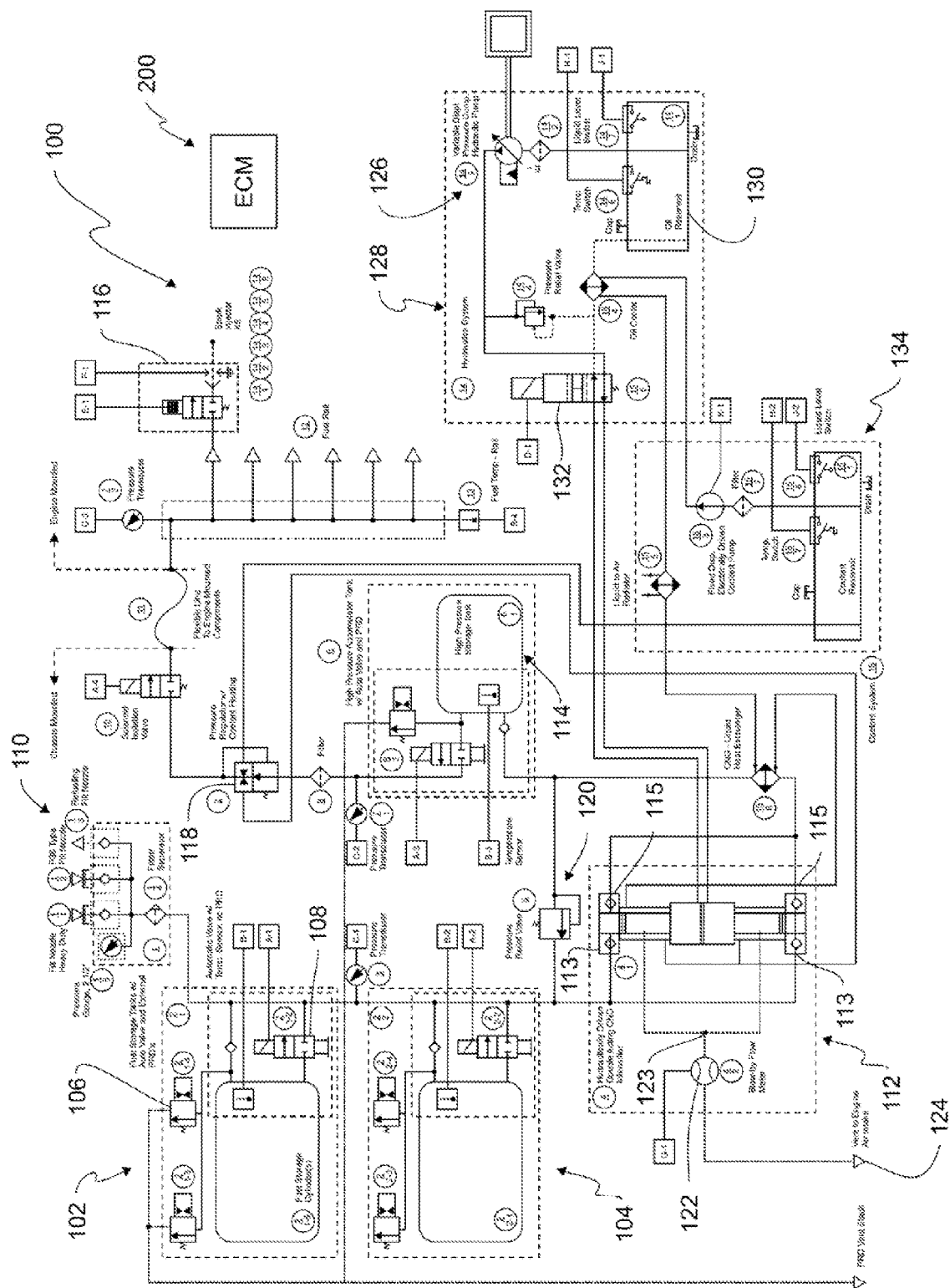
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HIGH PRESSURE DIRECT INJECTED GASEOUS FUEL SYSTEM AND RETROFIT KIT INCORPORATING THE SAME

BACKGROUND

Diesel engines have long been direct injected engines wherein fuel is injected at or near top dead center (TDC) directly into the combustion chamber. Many gasoline engines are now being developed as direct injected engines in order to take advantage of the efficiencies associated with direct injection. Direct injected gasoline engines are now possible due to advances in injector technology as well as advances in engine control strategy. However, direct injecting gaseous fuels such as natural gas or hydrogen have not yet gained similar feasibility.

One of the practical difficulties with using a gaseous fuel in a direct injected system is providing the fuel at a high enough pressure to be injected near top dead center while providing the necessary volume of fuel, which may be 3000 times the volume of operation on diesel fuel. Typical compressed natural gas (CNG) tanks are designed to contain fuel at approximately 3600 psi. In order to direct inject a gaseous fuel at or near top dead center, fuel must be at approximately 5800 psi. This high pressure is necessary in order to overcome the cylinder pressure under compression as well as to provide enough fuel into the cylinder.

Gaseous fuel has a lower energy density by volume when compared to diesel and gasoline, thus a much higher volume of fuel must be introduced into the cylinder in order to produce the same power. Existing infrastructure, tank technology, and fuel systems are designed around the standard 3600 psi system. Accordingly, there is a need for a gaseous fuel system capable of operating as a direct injected fuel system.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting and non-exhaustive embodiments of the devices, systems, and methods, including the preferred embodiment, are described with reference to the following FIGURE, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified.

FIG. 1 is a schematic representation of a high pressure direct injected gaseous fuel system.

DETAILED DESCRIPTION

The representative embodiments disclosed herein include a high pressure direct injected gaseous fuel system and retrofit kit incorporating the same. In one embodiment, the system comprises a fuel tank capable of storing fuel at a first pressure and a compressor including an inlet capable of receiving the fuel, and operative to supply, at an outlet, compressed fuel at a second pressure higher than the first. The system also includes an accumulator connected to the outlet and a plurality of injectors connected to the accumulator. The injectors are adapted to inject fuel directly into a combustion chamber. In some embodiments, the injectors are injector-igniters. The system may further include a pressure relief valve interconnecting the fuel tank and the outlet, wherein the pressure relief valve is operative to allow fuel flow between the fuel tank and outlet if the second pressure exceeds a threshold pressure.

In certain aspects of the disclosed technology, the compressor further comprises a blow-by vent and in some embodiments, the system is installed on an engine and the blow-by

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vent is connected to an intake of the engine. In other aspects of the technology, the compressor is powered by an engine driven hydraulic pump.

In another representative embodiment, a high-pressure direct injected gaseous fuel system includes a fuel tank capable of storing fuel at a first pressure and a compressor including an inlet capable of receiving the fuel, and operative to supply, at an outlet, compressed fuel at a second pressure higher than the first. The system further includes an accumulator connected to the outlet and a plurality of injector-igniters connected to the accumulator, wherein the injector-igniters are adapted to inject fuel directly into a combustion chamber. In addition, a pressure relief valve interconnects the fuel tank and the outlet, and is operative to allow fuel flow between the fuel tank and outlet if the second pressure exceeds a threshold pressure.

Also provided herein is a high pressure direct injected gaseous fuel system retrofit kit. In a representative embodiment, the kit comprises a compressor including an inlet capable of receiving fuel at a first pressure, and operative to supply, at an outlet, compressed fuel at a second pressure higher than the first. The kit can also include an electric motor or engine drivable hydraulic pump, operative to provide power to the compressor, an accumulator connectable to the outlet, and a plurality of injectors connectable to the accumulator, wherein the injectors are adapted to inject fuel directly into a combustion chamber. In other embodiments, the retrofit kit includes a pressure relief valve interconnectable to a fuel tank and the outlet, and operative to allow fuel flow between the fuel tank and outlet if the second pressure exceeds a threshold pressure.

In one aspect of the technology, the kit includes a fuel tank capable of storing fuel at a first pressure and connectable to the compressor. In other aspects, the hydraulic pump is engine mountable, and in still further aspects of the technology, the hydraulic pump is adapted to mount in place of or in conjunction with an engine-mounted fuel pump.

Specific details of several embodiments of the technology are described below with reference to FIG. 1. Other details describing well-known structures and systems often associated with ignition systems, fuel systems, and electronic valve actuation, such as fuel pumps, regulators, and the like, have not been set forth in the following disclosure to avoid unnecessarily obscuring the description of the various embodiments of the technology. Many of the details, dimensions, angles, steps, and other features shown in the figures are merely illustrative of particular embodiments of the technology. Accordingly, other embodiments can have other details, dimensions, angles, steps, and features without departing from the spirit or scope of the present technology. A person of ordinary skill in the art, therefore, will accordingly understand that the technology may have other embodiments with additional elements, or the technology may have other embodiments without several of the features shown and described below with reference to FIG. 1.

Some aspects of the technology described below may take the form of or make use of computer-executable instructions, including routines executed by a programmable computer or controller. Those skilled in the relevant art will appreciate that aspects of the technology can be practiced on computer systems other than those described herein. Aspects of the technology can be embodied in one or more special-purpose computers or data processors, such as an engine control unit (ECU), engine control module (ECM), fuel system controller, ignition controller, or the like, that is specifically programmed, configured, or constructed to perform one or more computer-executable instructions consistent with the tech-

nology described below. Accordingly, the term “computer,” “processor,” or “controller” as may be used herein refers to any data processor and can include ECUs, ECMs, and modules, as well as Internet appliances and hand-held devices (including diagnostic devices, palm-top computers, wearable computers, cellular or mobile phones, multi-processor systems, processor-based or programmable consumer electronics, network computers, mini computers and the like). Information handled by these computers can be presented at any suitable display medium, including a CRT display, LCD, or dedicated display device or mechanism (e.g., a gauge).

The technology can also be practiced in distributed environments, where tasks or modules are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules or subroutines may be located in local and remote memory storage devices. Aspects of the technology described below may be stored or distributed on computer-readable media, including magnetic or optically readable or removable computer disks, as well as distributed electronically over networks. Such networks may include, for example and without limitation, Controller Area Networks (CAN), Local Interconnect Networks (LIN), and the like. In particular embodiments, data structures and transmissions of data particular to aspects of the technology are also encompassed within the scope of the technology.

FIG. 1 illustrates a high pressure direct injected gaseous fuel system **100** according to a representative embodiment. In this embodiment, the fuel system **100** includes a pair of fuel storage tanks **102** and **104**, which in this case are configured to contain LPG and/or a gaseous fuel such as CNG or hydrogen, for example. Each tank **102** and **104** is coupled to the necessary safety devices such as pressure relief devices **106**, as well as the necessary control valves such as control valve **108**, all of which are well known in the art. In this embodiment, fuel tanks **102** and **104** are adapted to store gaseous fuel at approximately 3600 psi, which is typical of compressed natural gas. Tanks **102** and **104** are filled via one or more fill nozzles **110** as shown. Tanks **102** and **104** may include filters and/or suitable engine coolant and/or electric heaters to assure adequately rapid delivery of gaseous fuel.

Fuel flows from tanks **102** and **104** at a first pressure to compressor **112** which is operative to compress the fuel. Compressor **112** includes inlets **113** capable of receiving fuel from the fuel tanks **102** and **104** and is operative to supply at outlets **115** compressed fuel at a second pressure higher than the first pressure. For example, compressor **112** receives fuel from tanks **102** and **104** at approximately 3600 psi and provides compressed fuel at approximately 5800 psi. Compressor **112** provides the high pressure fuel to accumulator **114** which is connected to outlets **115**. Accumulator **114** in turn supplies a plurality of injectors **116**.

Injectors **116** are adapted to inject a gaseous fuel directly into a combustion chamber. Injectors **116** may be in the form of injector-igniters such as those described in co-pending U.S. patent application Ser. No. 12/653,085, filed Dec. 7, 2009, the disclosure of which is incorporated herein by reference in its entirety. Injector-igniters may be particularly desirable in a retrofit kit in order to provide spark as well as fuel in the confined spaces of an existing cylinder head. A pressure regulator **118** is connected between accumulator **114** and the plurality of injectors **116**, and functions to supply fuel at a constant pressure to the injectors **116**. Fuel system **100** also includes a pressure relief valve **120** interconnected between the fuel tanks **102**, **104** and the outlets **115** of compressor **112**. The pressure relief valve **120** is operative to allow fuel flow between outlets **115** and fuel tanks **102** and

104, if the second pressure exceeds a threshold pressure. Accordingly, pressure relief valve **120** is operative to prevent over-pressurization of the accumulator **114** and the downstream fuel injection system. In the event that pressure exceeds the threshold pressure, the high pressure coming from the outlets **115** is vented back to the lower pressure tanks **102** and **104**.

In some embodiments, the compressor **112** is a hydraulically-driven double-acting intensifier. Other suitable compressors as are known in the art may also be used. In an embodiment, compressor **112** includes a blow-by vent **123** to accommodate blow-by and leakage often associated with piston compression pumps. Any fuel vented through blow-by vent **123** flows through a blow-by flow meter **122** and is vented into the air intake **124** of an associated engine. Thus, rather than venting fuel to the atmosphere, the fuel is fed into the engine where it is burned in due course. Accordingly, because fuel is entering the intake system, the fuel injection system must account for the additional fuel in the air. To that end, the blow-by flow meter **122** communicates with an engine control module **200**, which in turn adjusts the amount of fuel injected by fuel injectors **116** to the engine.

In this embodiment, compressor **112** is powered by an engine-driven hydraulic pump **126**. The hydraulic pump **126** is part of an associated hydraulic system **128** which includes a tank **130** and the necessary control valves such as control valve **132**. The fuel system **100** may also include a cooling system **134** in order to cool the compressed fuel at the outlets **115** from compressor **112**. Cooling system **134** may also cool the hydraulic fluid used to power the compressor **112**. It may also be used to heat a pressure regulator **118** in order to prevent freezing due to expansion of fuel therethrough.

The fuel system **100** as described above may also be the basis for a retrofit kit to convert diesel engines to run on alternative fuels such as compressed natural gas. Accordingly, various combinations of the above described components may be packaged and provided as a kit in order to convert such vehicles. For example, in one embodiment, a high-pressure direct injected gaseous fuel system retrofit kit includes a compressor **112**, an engine-drivable hydraulic pump **126**, an accumulator **114**, and a plurality of injectors **116**. In other embodiments, the kit may also include a pressure relief valve **120** that is interconnectable between the fuel tank and outlet. In still further embodiments, the kit may include one or more fuel tanks capable of storing fuel. In some embodiments hydraulic pump **126** is engine mountable and is adapted to mount in place of an engine mounted fuel pump. In other embodiments, the kit may also include pressure regulator **118**. In still further embodiments, the kit may include all necessary fittings, valves, tubing, wiring and control modules such as shown in FIG. 1.

From the foregoing, it will be appreciated that, although specific embodiments of the technology have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the technology. Further, certain aspects of the new technology described in the context of particular embodiments may be combined or eliminated in other embodiments. Moreover, while advantages associated with certain embodiments of the technology have been described in the context of those embodiments, other embodiments may also exhibit such advantages, and not all embodiments need necessarily exhibit such advantages to fall within the scope of the technology. Also contemplated herein are methods which may include any procedural step inherent in the structures and systems described. Accordingly, the disclosure and associated technology can encompass other embodiments not expressly

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shown or described herein. The following examples provide additional embodiments of the present technology.

EXAMPLES

1. A high-pressure direct injected gaseous fuel system, comprising:

a fuel tank capable of storing fuel at a first pressure;
a compressor including an inlet capable of receiving the fuel, and operative to supply, at an outlet, compressed fuel at a second pressure higher than the first;
an accumulator connected to the outlet; and
a plurality of injectors connected to the accumulator, wherein the injectors are adapted to inject fuel directly into a combustion chamber.

2. The system of example 1, further comprising a pressure relief valve interconnecting the fuel tank and the outlet.

3. The system of example 2, wherein the pressure relief valve is operative to allow fuel flow between the fuel tank and outlet if the second pressure exceeds a threshold pressure.

4. The system of example 1, wherein the compressor further comprises a blow-by vent.

5. The system of example 4, wherein the system is installed on an engine and the blow-by vent is connected to an intake of the engine.

6. The system of example 1, wherein the injector is an injector-igniter.

7. The system of example 1, wherein the compressor is powered by an engine driven hydraulic pump.

8. A high-pressure direct injected gaseous fuel system, comprising:

a fuel tank capable of storing fuel at a first pressure;
a compressor including an inlet capable of receiving the fuel, and operative to supply, at an outlet, compressed fuel at a second pressure higher than the first;
an accumulator connected to the outlet;
a plurality of injector-igniters connected to the accumulator, wherein the injector-igniters are adapted to inject fuel directly into a combustion chamber; and
a pressure relief valve interconnecting the fuel tank and the outlet, and operative to allow fuel flow between the fuel tank and outlet if the second pressure exceeds a threshold pressure.

9. The system of example 8, wherein the compressor further comprises a blow-by vent.

10. The system of example 9, wherein the system is installed on an engine and the blow-by vent is connected to an intake of the engine.

11. The system of example 10, wherein the compressor is powered by a hydraulic pump driven by the engine.

12. A high-pressure direct injected gaseous fuel system retrofit kit, comprising:

a compressor including an inlet capable of receiving fuel at a first pressure, and operative to supply, at an outlet, compressed fuel at a second pressure higher than the first;
an electric motor or engine drivable hydraulic pump, operative to provide power to the compressor;
an accumulator connectable to the outlet; and
a plurality of injectors connectable to the accumulator, wherein the injectors are adapted to inject fuel directly into a combustion chamber.

13. The retrofit kit of example 12, further comprising a pressure relief valve interconnectable to a fuel tank and the outlet, and operative to allow fuel flow between the fuel tank and outlet if the second pressure exceeds a threshold pressure.

14. The retrofit kit of example 12, further comprising a fuel tank capable of storing fuel at a first pressure and connectable to the compressor.

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15. The retrofit kit of example 12, wherein the injectors are injector-igniters.

16. The retrofit kit of example 12, wherein the compressor further comprises a blow-by vent.

17. The retrofit kit of example 16, wherein the blow-by vent is connectable to an intake of an engine.

18. The retrofit kit of example 12, wherein the hydraulic pump is engine mountable.

19. The retrofit kit of example 18, wherein the hydraulic pump is adapted to mount in place of an engine mounted fuel pump.

20. The retrofit kit of example 12, further comprising a pressure regulator connectable between the accumulator and the plurality of injectors.

We claim:

1. A high-pressure direct injected gaseous fuel system, comprising:

a fuel tank capable of storing fuel at a first pressure;
a compressor comprising an inlet capable of receiving the fuel, and operative to supply, at an outlet, the fuel at a second pressure higher than the first pressure;
an accumulator in fluid communication with the outlet to receive and to store the compressed gaseous fuel from the compressor and in fluid communication with the inlet through a pressure regulator to convey excess compressed gaseous fuel to the compressor;
a pressure relief valve interconnecting the fuel tank and the outlet, and operative to allow fuel flow between the fuel tank and outlet if the second pressure exceeds a threshold pressure; and
a plurality of injectors connected to the accumulator, wherein the injectors are adapted to inject the fuel directly into a combustion chamber.

2. The system of claim 1, wherein the compressor further comprises a blow-by vent in fluid communication with the compressor and an air intake of the engine to vent excess gaseous fuel within the compressor due to compressor blow-by and leakage directly to the air intake.

3. The system of claim 1, wherein the injector comprises an injector-igniter.

4. The system of claim 1, further comprising an engine driven hydraulic pump connected to the compressor.

5. A high-pressure direct injected gaseous fuel system, comprising:

a fuel tank capable of storing fuel at a first pressure;
a compressor comprising an inlet capable of receiving the fuel, and operative to supply, at an outlet, the fuel at a second pressure higher than the first pressure;
an accumulator in fluid communication with the outlet to receive and to store the compressed gaseous fuel from the compressor and in fluid communication with the inlet through a pressure regulator to convey excess compressed gaseous fuel to the compressor;
a plurality of injector-igniters connected to the accumulator, wherein the injector-igniters are adapted to inject the fuel directly into a combustion chamber; and
a pressure relief valve interconnecting the fuel tank and the outlet, and operative to allow fuel flow between the fuel tank and outlet if the second pressure exceeds a threshold pressure.

6. The system of claim 5, wherein the compressor further comprises a blow-by vent in fluid communication with the compressor and an air intake of the engine to vent excess gaseous fuel within the compressor due to compressor blow-by and leakage directly to the air intake.

7. The system of claim 5, wherein the compressor is powered by a hydraulic pump driven by the engine.

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8. A high-pressure direct injected gaseous fuel system retrofit kit, comprising:

- a compressor comprising an inlet capable of receiving fuel at a first pressure, and operative to supply, at an outlet, the fuel at a second pressure higher than the first pressure, the compressor further comprising a blow-by vent connectable to an intake of an engine;
- an engine drivable hydraulic pump, operative to provide power to the compressor;
- an accumulator in fluid communication with the outlet to receive and to store the compressed gaseous fuel from the compressor and in fluid communication with the inlet through a pressure regulator to convey excess compressed gaseous fuel to the compressor; and
- a plurality of injectors connectable to the accumulator, wherein the injectors are adapted to inject the fuel directly into a combustion chamber.

9. The retrofit kit of claim **8**, further comprising a pressure relief valve interconnectable to a fuel tank and the outlet, and operative to allow fuel flow between the fuel tank and outlet if the second pressure exceeds a threshold pressure.

10. The retrofit kit of claim **8**, further comprising a fuel tank capable of storing fuel at a first pressure and connectable to the compressor.

11. The retrofit kit of claim **8**, wherein the injectors comprise injector-igniters.

12. The retrofit kit of claim **8**, wherein the hydraulic pump is engine mountable.

13. The retrofit kit of claim **12**, wherein the hydraulic pump is adapted to mount in place of an engine mounted fuel pump.

14. The retrofit kit of claim **8**, further comprising a pressure regulator connectable between the accumulator and the plurality of injectors.

15. A high-pressure direct injected gaseous fuel system, comprising:

- a fuel tank capable of storing gaseous fuel at a first pressure;
- a compressor in fluid communication with the fuel tank, wherein the compressor comprises an inlet capable of

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receiving the gaseous fuel from the fuel tank, and operative to supply, at an outlet, compressed gaseous fuel at a second pressure higher than the first pressure;

- an accumulator in fluid communication with the outlet to receive and to store the compressed gaseous fuel from the compressor and in fluid communication with the inlet through a pressure regulator to convey excess compressed gaseous fuel to the compressor;

a plurality of injectors in fluid communication with the accumulator, wherein the plurality of injectors are adapted to inject the compressed gaseous fuel from the accumulator directly into a combustion chamber of an engine;

a blow-by vent in fluid communication with the compressor and an air intake of the engine to vent excess gaseous fuel within the compressor due to compressor blow-by and leakage directly to the air intake; and

a blow-by flow meter in communication with the blow-by vent and an engine communication module, such that the engine control module can adjust amount of the compressed gaseous fuel from the accumulator injected by the plurality of injectors into the combustion chamber of the engine to account for the excess compressed gaseous fuel directly vented to the air intake from the blow-by vent.

16. The system of claim **15**, wherein the injector comprises an injector-igniter.

17. The system of claim **15**, further comprising an engine driven hydraulic pump connected to the compressor.

18. The system of claim **15**, further comprising a pressure relief valve interconnectable to the fuel tank and the outlet, and operative to allow fuel flow between the outlet and the fuel tank if the second pressure exceeds a threshold pressure.

19. The system of claim **15**, further comprising a pressure regulator connectable between the accumulator and the plurality of injectors.

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